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Cycling and ecosystem impact of metals in contaminated calcareous dredged sediment-derived soils (Flanders, Belgium)

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ABSTRACT

Significant areas in Flanders, Belgium exhibit moderate contamination with trace metals caused by disposal of contaminated dredged sediments. After disposal, the sediments develop into a soil-like material, on which vegetation is planted or develops spontaneously. Behaviour, cycling and ecosystem impacts of trace metals in calcareous dredged sediment disposal sites in Flanders is reviewed. Although soil physico-chemical properties favour a low metal bioavailability, pore water concentrations can be elevated compared to pore water in uncontaminated soils. While metal leaching is not considered to be of concern, several plants accumulate elevated levels of Cd and Zn in leaves. Also metal levels in soil dwelling organisms and small mammals, particularly Cd, are elevated compared to reference situations. This raises concern for an enhanced transfer of metals to the food chain. Future research should identify biological effects on organisms caused by the contamination. A comprehensive knowledge of metal behaviour in these sites is essential for developing appropriate management options for these sites.

1. Introduction

Water bodies carry suspended matter that originates from erosion processes upstream. This material eventually is deposited as a layer of solid particles on the bed of the water body. Dredging involves the removal of these sediments in order to initiate infrastructural or ecological improvements. It can have different objectives. 'Maintenance dredging' is aimed at maintaining a sufficient depth of water for navigation (Bramley and Rimmer, 1988). The activity is referred to as 'capital dredging' when it aims at increasing for the first time the natural depth of a water body. Civil engineering work may also create a demand for dredging, while 'environmental dredging' is primarily concerned with remedying water bodies by removal of contaminated bottom sediments (Yell and Riddell, 1995). Undisturbed sediments and natural sedimentation processes have a net scavenging effect on most chemical pollutants that enter into waterways (Bramley and Rimmer, 1988). As a result, sediments dredged from waterways and harbours frequently exhibit elevated concentrations of metals and other pollutants compared to baseline levels in surface soils. This represents a serious problem because it limits the options for subsequent handling of the sediments.

Once dredged, sediments must be transported and relocated. Traditionally, sediments dredged from inland water bodies were disposed along the shores and on agricultural land. In Flanders, between the 1970s and 2000, sediments have been disposed in confined disposal facilities (Vandecasteele et al., 2002c; Vervaeke et al., 2001). The dredged materials are hydraulically pumped into the sites. Sediments settle down, while the excess of supernatant water flows out of the site though installed outlets. The sediments remain covered by a layer of water and are therefore kept in a reduced state during the period that the site is in use. When sediment introduction ceases, the water cover will disappear provided evaporation exceeds input through precipitation. The sediments gradually

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dry and oxidise. Depending on specific site characteristics, this might take between a few weeks to several years. Wetland plants such as certain willow species may already have colonized the site. Gradual terrestrialisation of the site affects sediments properties and causes the ecosystem that develops on it to adapt to the changing conditions (Vandecasteele et al., 2007).

These ecosystems are exposed to the elevated total metal concentrations in the substrate. Metals can become mobile, and leach to the underground or be exported with run-off. They might be taken up by vegetation and be recycled to the litter through leaf fall. Soil dwelling organisms exposed to high metal levels in the substrate might accumulate metals in their tissues. Over the last decade, a substantial body of research has become available on metals in dredged sediment-derived soils in Flanders. Studies have focussed on metal geochemistry (Singh et al., 1996, 1998; Tack et al., 1996, 1998)), short rotation forestry (Meers et al., 2003; Vervaeke et al., 2001, 2003), afforestation (Mertens et al., 2007; Vandecasteele et al., 2008), wetland conservation on landfilled dredged sediments (Vandecasteele et al., 2005c) or landscape dikes with dredged material (Mertens et al., 2004; Piesschaert et al., 2005). This research constitutes a unique comprehensive case study that allowed to acquire a clear picture on the extent of metal cycling and on effects on vegetation and fauna in ecosystems developing on calcareous dredged sediment-derived soils.

2. Characteristics of dredged sediment-derived soils in Flanders

In comparison with unaffected alluvial soils, the most distinguishing properties for dredged sediment-derived soils in Flanders are elevated levels of calcium carbonate, sulphur, organic carbon and phosphorous, a relatively high electrical conductivity, and relatively small C/S and C/P ratios (Vandecasteele et al., 2002b) (Table 1). Significant carbonate levels cause the soils to have a neutral to slightly alkaline reaction (Singh et al., 1998; Vandecasteele et al., 2002b). Free carbonates have an important role in buffering the acidity that is produced during oxidation of reduced dredged materials. Such acidification is mainly caused by oxidation of sulphides (Satawathananont et al., 1991) and might explain a 2 to 4% decrease in the carbonate content of dried and oxidised dredged sediment (Tack et al., 1996). In the absence of free carbonates, drying and oxidising sediments may exhibit a sharp drop in pH. For example, in a contaminated canal sediment in NW England, the pH decreased from 6.7 to 3.7 over a period of 48 days (King et al., 2006). Accelerated conditioning of sediment from the Weisse Elster river, Germany, using plants was hampered because of a drop in pH from 7 to 5 associated with a strong release of metals (Löser et al., 2002).

An elevated sulphur content is a feature of dredged sediment-derived soils which is atypical for upland soils in general. Median levels around 2.3 g kg^{-1} S were encountered (Table 1), whereas upland soils normally contain between 0.1 and 0.5 g kg^{-1} of S, of which most is in organic form (Tabatabai, 1982). Sulphide is the dominant form of sulphur in reduced sediments. During drying and oxidation, sulphide is gradually converted to oxidised sulphur forms. It is ultimately converted to sulphate, which is susceptible to leaching. With time, sulphur contents will tend to decrease. In a lab scale experiment, a reduced sediment containing 13 mg kg^{-1} sulphide was allowed to dry and oxidise. Over a period of 30 days, all sulphide was converted to intermediary oxidised sulphur forms (50%) and sulphate (50%) (Tack et al., 1997a). Also the experiments of Stephens et al. (2001) have clearly illustrated the gradual oxidation of sulphide during drying of a dredged sediment over a period of a few weeks (Stephens et al., 2001). In the field, a significantly lower sulphur content was found in the oxidized top layer (2.9 mg kg^{-1}) compared to the underlying reduced sediment (4.3 mg kg^{-1}) (Vandecasteele et al., 2002b).

Table 1 – Properties of dredged sediment-derived soils along the rivers Scheldt and Leie [a]

	Median	Min	P10 [b]	P90 [c]	Max
Clay (0–2 μm; %)	35	12	21	45	55
Silt (2–50 μm; %)	47	18	35	57	64
Sand (>50 μm; %)	16	0	3	43	69
P (g kg^{-1})	2.8	0.5	1.2	4.2	5.9
N (g kg^{-1})	2.4	0.7	1.3	3.5	6.8
S (g kg^{-1})	2.3	0.5	1.0	5.7	15
$CaCO_3$ (g kg^{-1})	72	32	49	94	133
OC (g kg^{-1})	51	20	29	76	104
pH–H_2O	7.5	7.0	7.3	7.8	8.1
pH–$CaCl_2$	7.2	6.7	7.0	7.5	7.7
EC (mS/cm)	0.52	0.13	0.18	1.69	2.33

[a] Compiled as the average of summary statistics given for Upper Scheldt (Vandecasteele et al., 2002c), Sea Scheldt (Vandecasteele et al., 2003a) and Leie (Vandecasteele et al., 2004a), covering 432 observations.
[b] 10% percentile.
[c] 90% percentile.

Table 2 – Ranges (minimum–maximum) and median value for trace element concentrations in dredged sediment-derived soils compared with baseline concentrations in Flanders

Description	*n*	Cd	Cr	Cu	Ni	Pb	Zn	Ref.
		mg/kg dry sediment						
Upper Scheldt [a]	162	0.5–47	31–2800	5–320	7–70	5–1300	63–4200	1
		14.5	1200	125	33	220	1880	
Leie river [a]	139	0.3–26	35–1800	18–510	11–140	35–1100	77–3800	2
		9.9	230	180	45	344	1400	
Sea Scheldt [a]	131	0.5–25	29–2400	9–1700	6–78	11–680	54–4400	3
		4.2	270	110	24	210	900	
Reference [b]		0.6–2	37–77	17–29	6–15	38–68	56–101	4

1 (Vandecasteele et al., 2002c).
2 (Vandecasteele et al., 2004a).
3 (Vandecasteele et al., 2003a).
4 (Tack et al., 1997b).
[a] Minimum, maximum and median value.
[b] Baseline concentration levels in upland soils in Flanders (Belgium); range for 95% percentile depending on clay and organic matter content of the soil.

3. Metal contents, fractions and extractability

Trace metal contamination of water bodies will effectively be immobilized in bottom sediments. Accordingly, total trace metal contents in dredged sediment-derived soils tend to be significantly higher than baseline metal levels in uncontaminated upland soils (Table 2). Vandecasteele et al. (2002c) appraised the contamination level of the sites along the Upper Scheldt river by comparing element concentrations with risk based standard values for soil remediation in Flanders. In 86% of the 162 sampling points, soil remediation standard values were exceeded for at least one of the metals. Compared to remediation standard values, concentrations of Cr, Cd and Zn indicated severe pollution. Contamination with Pb was markedly less severe, while levels of Cu and Ni were well below remediation standard values, though still systematically above baseline level concentrations in the region (Vandecasteele et al., 2002c).

The environmental behaviour of trace metals is primarily determined by their specific physico- chemical forms rather than by their total concentrations (Bernhard et al., 1986; Nelson and Donkin, 1984). Sequential extraction procedures have been developed to differentiate between pools of different reactivity. The fractionation of the total metal contents of a typical calcareous dredged sediment-derived soil in Flanders according to the three step BCR sequential extraction procedure is illustrated in Fig. 1.

The sequence of fractions reflects increasingly aggressive conditions (Hickey and Kittrick, 1984; Keller and Védy, 1994). The residual fraction, consisting of metals retained within the crystal lattice of minerals and well-crystallised oxides is considered to be immobile (Tessier et al., 1979). Non-residual contents in sequential extraction procedures have been shown to correlate well with dilute HCl extractions (Sutherland, 2002). About 90% of Zn and Cd, and 80% of Ni in the dredged sediment-derived soil was in such labile (potentially mobile) phases. Labile Cu and Pb amounted up to 60% (Fig. 1).

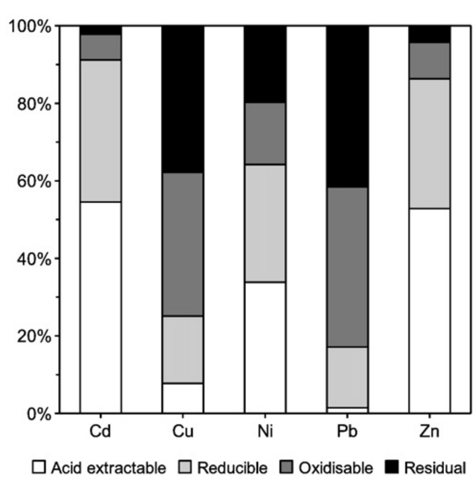

Fig. 1 – Fractionation of total element contents according to the three step BCR procedure in dredged sediment-derived soil at Meigem (total contents in mg kg^{-1} dry sediment: Cd: 17; Cu: 210; Pb: 274; and Zn: 1450) (Singh et al., 1998).

Cadmium and Zn have a comparable environmental behaviour (Smies, 1983), which is reflected in their similar distributions between the different fractions. Their association with the acid-extractable and reducible fractions suggests that they were either sorbed on various solid phases or associated with carbonates and Fe–Mn oxides (Fergusson and Kim, 1991; Hickey and Kittrick, 1984; Tessier et al., 1979). The overall stronger binding of Pb and Cu is reflected in a stronger association with the subsequent fractions in the sequential extraction procedure. The important oxidisable fraction suggests a strong association with organic matter. The organic fraction is rather immobile because it is mostly associated with stable high molecular weight humic substances (García-Miragaya and Sosa, 1994).

While the different fractions might to an extent reflect metal pools that can be released in changing conditions of pH and redox over the long-term, their correlation with biological effects is less clear. Single reagent extractions have been widely used for assessing the potential bioavailability of metals in the field (Bryan and Langston, 1992). Extractability of Cd, Mn and Zn in dredged sediment-derived soils decreased in the order NH_4OAC-EDTA>HCl>DTPA>NH_4OAC>$CaCl_2$. For Cu and Pb, larger amounts were extracted with the complexing agent DTPA than with HCl (Singh et al., 1998), illustrating the importance of complex formation in the mobilisation of these elements (Norvell, 1984). DTPA-extractable metals, which may be considered indicative of plant-available contents, were relatively high compared to the total contents and suggested that any of the studied sites would be of concern if they were used for agricultural activities (Singh et al., 1998). To complement chemical extraction techniques, physical analytical techniques are currently emerging and are proving to be promising tools to help elucidating chemical forms of occurrence of trace elements quantitatively and specifically. Using these approaches the nature of Zn species in a highly contaminated land disposed dredged sediment from North-France was comprehensibly assessed (Isaure et al., 2002; Panfili et al., 2005). The major Zn forms were ZnS and Zn-containing Fe (oxyhydr)oxides, while a minor species was represented by Zn-containing phyllosilicate (Isaure et al., 2002).

4. Solubility and leaching of metals

Metal mobility and availability are much related to the composition of the liquid phase. Concentrations of several metals in the saturation extracts of oxic dredged sediment-derived soils in the region of Ghent were markedly above levels considered representative for pore water of clean soils, between 5–10 μg l^{-1} for Cd, 60–200 μg l^{-1} for Cu, and 300–1000 μg l^{-1} for Zn (Tack et al., 1998). Pore water metal concentrations might fluctuate as a function of the moisture regime in the soil among other factors (Du Laing et al., 2007). Trace metal levels in solution typically decrease below the μg l^{-1} level when reducing conditions are established, which is caused by their association with sulphides (Du Laing et al., 2007; Tack et al., 1998). Alternated flooding causes pore water concentrations to fluctuate. This behaviour is largely caused by the reduction and reoxidation of hydrated oxides of Fe and Mn, and of sulphide, where the importance and intensity of these different

processes depend on the length and frequency of the flooding cycles (Du Laing et al., 2007).

Leaching of metals from disposed dredged materials to the underground is greatly retarded because of the low hydraulic permeability of the substrates and the strong adsorption of metals. It was estimated that migration of metals from dredged sediment-derived surface soil could result in yearly increases of total metal concentrations in 50 cm of underlying soil in the order of 2–4 μg kg^{-1} for Cd and Pb, 20–80 μg kg^{-1} for Cu and 100–500 μg kg^{-1} for Zn (Tack et al., 1998). From long-term leaching experiments using cascade leaching tests, the extent and importance of leaching was predicted to be of little concern. For example, accumulation of Cd after 500 years in a sandy soil was projected to be on average 0.05 mg kg^{-1} over a depth of 2.5 m. In a clay soil, the amount of metals released after 500 years would be retained in 40 cm of underlying soil, with an average accumulation of 0.5 mg kg^{-1} (Tack et al., 1999). The elevated acid neutralizing capacity of the dredged sediment-derived soils, which is effectuated by free $CaCO_3$ strongly decreases the chance of soil acidification with associated heavy metal leaching over the long-term (Cappuyns et al., 2004).

5. Uptake and distribution of metals in vegetation

Ripened dredged materials are an excellent substrate for vegetation because of their favourable physical properties and chemical fertility (Bramley and Rimmer, 1988; Darmody and Marlin, 2002). Recycling of elements through litter fall and litter decomposition can be an important pathway for input into the food web (Mertens et al., 2004). Hence, uptake of metals in vegetation that develops on dredged sediment-derived soils may be of concern. Appropriate management practices for these lands must aim at minimizing the risk of contaminant dispersal into the environment. Recent research focussed on appropriate choice of tree species and use of thin capping layers as management options, and on effects of metals on litter decomposition (Mertens et al., 2007; Vandecasteele et al., 2005a, 2008).

Although general properties of the dredged sediment-derived soils in Flanders – presence of free carbonates, neutral pH, high organic matter and clay contents – favour low mobility and bioavailability of metals, some plants can exhibit elevated metal concentrations in the above ground parts (Capilla et al., 2006; Vandecasteele et al., 2002a). Willow (*Salix* sp.) naturally invades dredged sediment landfills. It is the climax vegetation on freshwater tidal marshes and other sediment-derived substrates contaminated with metals (Vandecasteele et al., 2006; Vervaeke et al., 2001). Foliar Cd and Zn concentrations in willow (>6.6 mg Cd kg^{-1} DW and >700 mg Zn kg^{-1} DW) were elevated compared to concentrations observed in reference situations (0.5–2.9 and 128–338 mg kg^{-1} DW for Cd and Zn, respectively) (Vandecasteele et al., 2002a). Still, favourable effects of the sediment-derived substrate in restricting metal uptake can be shown using data from a greenhouse experiment. Foliar concentrations of Cd in *Salix dadyclados* 'Loden' were in the order of 10 mg kg^{-1} when grown on a dredged sediment-derived soil with a Cd content of 8.8 mg kg^{-1}. The same willow clone grown in similar conditions on a pH-neutral sandy soil with a Cd content of 5.5 mg kg^{-1} Cd exhibited lower biomass production (−40%) and foliar Cd concentrations of over 30 mg kg^{-1} dry matter (Meers et al., 2007).

Also poplar tends to exhibit elevated Cd and Zn concentrations when growing on polluted dredged sediment-derived soils (Vandecasteele et al., 2003b). Leaves of maize grown on contaminated dredged sediment-derived soils contained high levels of Zn and Cd, which were correlated with total metal concentrations in the soils (Vandecasteele et al., 2006). Other plants, such as ash, alder, maple and Robinia, do not accumulate metal levels in excess to these encountered in a not contaminated environment (Mertens et al., 2004; Vandecasteele et al., 2002a). Even between different clones of the same species, metal uptake may greatly differ. This has been extensively shown for willow (Greger and Landberg, 1999) and was also observed for poplar (Laureysens et al., 2004).

Metal concentrations in willow biomass compartments on oxidised sediments tend to decrease with stand age. This can be attributed to metal accumulation occurring most in actively growing tissues such as shoots and young leaves. Another factor is that accumulated metals are diluted with increased biomass production (Mertens et al., 2006). Especially in young vegetation, concentrations of Cd and Zn in leaves, wood and bark strongly increase towards the end of the growing season (Mertens et al., 2006; Vandecasteele et al., 2005c).

The hydrological condition of a site has a great influence on the availability of trace elements for uptake by plants. An upland hydrological regime resulted in elevated Cd and Zn concentrations in leaves of *Salix cinerea*, whereas concentrations were normal in a wetland hydrological regime (Vandecasteele et al., 2005c). Longer submersion periods in the field caused lower Cd and Zn concentrations in the leaves in the first weeks of the growing season. Emergence then sharply increased foliar concentrations to levels comparable with the plots that were already emerged at the beginning of the growing season. On a site subject to gradual dewatering and terrestrialisation, Cd, Zn and Mn concentrations in leaves increased during subsequent growing seasons (Vandecasteele et al., 2007). Especially for Cd, a transfer effect from one growing season to the next season was observed. Oxic conditions at the end of the previous growing season seemed to determine at least partly the foliar concentrations for *S. cinerea* during the next growing season (Vandecasteele et al., 2005b). Maintaining a hydrological regime aiming at wetland creation is a potential management option for reducing bioavailability provided submersion can be maintained throughout the growing season (Vandecasteele et al., 2005b).

6. Forest floor decomposition and soil forming processes

Vegetation has different impacts on the mobility and bioavailability of trace elements present in dredged sediment-derived soils. The intensity of effects differs among plant species and may involve (Marseille et al., 2000): increase in redox potential due to the mechanical action of plant roots, thus enhancing the oxidation of the sediments and the release of trace metals; decrease of pH in the rhizosphere due to microbial activity and

production of acids by vegetation; increase in dissolved organic matter that act as ligands for trace metals and enhance their mobility; and increase of the sediment micro-biological activity causing an intensified turnover of organic matter and thus an accelerated cycling of the associated trace metals. Vegetation also has an indirect effect through litter fall.

Extractability of Cd, Zn, and Cu in the rhizosphere increased, whereas that of Pb decreased after 75 days of willow root growth (Vervaeke et al., 2004). This was attributed to the increased willow-induced oxidation rate in the root zone as a result of aeration and evapotranspiration, which was more dominant than the direct chemical and biological influences of the willow roots. Two years of willow root growth had significant effects on the chemical characteristics and metal contents of the sediment. Metal concentrations were significantly lower in the root zone. The extractability of Cd, Cu, and Pb was greater in the rhizosphere than in the bulk sediment, showing that more metals were becoming directly available for leaching through the root zone (Vervaeke et al., 2004).

The forest floor acts as a sink for contaminants and determines their fate. The forest floor mass and especially the decomposition rate can be considered important indicators of long-term adverse effects of metal contamination (Laskowski et al., 1995). No adverse effects on forest floor decomposition were observed in a dredged sediment disposal site after 16 years of landfilling and 12 years of afforestation. Soil processes had resulted in only small differences between the surface and the subsurface soil layer, with minor impact of tree species (Vandecasteele et al., 2005a). This might indicate that the soil nutrition status and the high carbonate status override the negative impact of the contamination.

Effects from different tree species become apparent over the longer term (Mertens et al., 2007). Two processes appear to determine soil metal concentrations in the upper layer: accumulation in the leaves and species-specific soil acidification. Soil and biomass were sampled 33 years after planting four tree species in a plot experiment on dredged sediment. Poplar took up high amounts of Cd and Zn. This was reflected in increased Cd and Zn concentrations in the upper soil layer, caused by the high metal contents in leaf fall. The other species contained normal concentrations of Cd, Cu, Cr, Pb and Zn in their tissues. Oak acidified the soil more than the other species. A decrease in the concentration of metals in the upper soil layer might be attributed to an increased leaching. While leaf litter from poplars and willows generally decomposes rapidly (mull type humus), the pH under poplar was lower than expected and associated with high carbon concentrations in the top soil. It was hypothesised that this was caused by retardation in the litter decomposition due to elevated Cd and Zn concentrations (Mertens et al., 2007).

7. Effects on biota

Uptake by plants and leaf fall will cause metals in the dredged sediment-derived soil to cycle through the ecosystem developing on it. The extent of the resulting ecosystem effects ultimately will determine acceptable management options for these areas. It was observed that different organisms accumulate markedly higher metal levels in ecosystems developed on contaminated dredged sediment-derived soils compared to unpolluted environments. Leaf beetles on poplars showed higher body Cd concentrations than in reference situations. Zn levels in the leaf beetles were in the normal range, although both Zn and Cd in the poplar leaves were elevated (Vandecasteele et al., 2003b).

Earthworms have an important role in the biomagnification of heavy metals in terrestrial ecosystems. Relative to the surrounding environment, earthworm biomass was four times lower for contaminated heavy clay dredged sediment-derived soils and comparable for sandy loam dredged sediment-derived soils. Risks for secondary poisoning at the more polluted heavy clay dredged sediment-derived soils were thus partially compensated for by the lower earthworm biomass (Vandecasteele et al., 2004b). In addition to the earthworm biomass, there are differences in susceptibility to predation between different categories of earthworms. Endogeic earthworms remain in the soil, while anecic earthworms are only at night at the soil surface. For a good risk assessment of biomagnification, earthworm tissue concentrations, earthworm biomass and prevalent species must be taken into consideration (Vandecasteele et al., 2004b).

Terrestrial gastropods are another very important group of organisms in determining transfer of metals from vegetation or plant litter to carnivores. Shells of *C. nemoralis* had increased levels of Cd and Zn whereas the levels of Cr and Pb remained below the limit of detection, despite elevated contents of these metals in the dredged sediment-derived soils. While elevated Cd and Zn concentrations in the shells may be directly related to high Cd and Zn concentrations in the soils, vegetation, forest floor composition and food preference may also affect the bioavailability of metals. Although there was substantial variation in shell strength, thickness and dry weight among locations, none of these shell traits could be clearly linked to the trace element contamination level. (Jordaens et al., 2006).

Mertens et al. (2001) analysed small mammals living in disposal sites for dredged sediment. Levels of Cd, but not Zn, in small mammals (wood mouse, bank vole and common shrew) were elevated compared with background levels. There were no significant differences between sites in Cd or Zn levels in animals, despite differences in soil contaminant levels and concentrations in willow leaves. Risk assessment suggested that the Cd in the soil would cause a limited risk for predators (Mertens et al., 2001). High Cd levels were observed in white-footed mice living in a sediment disposal site at Illinois, USA (Levengood and Heske, 2008). However, no impact of the metal exposure on population parameters could be demonstrated. High concentrations in vegetation and small mammals nevertheless indicate that ecosystem development should be considered carefully.

8. Summary and conclusion

Over the last decade, considerable research has focussed on ecosystems, developed on disposed contaminated calcareous dredged sediments in Flanders. It has allowed to appraise the extent of the hazard associated with the metal concentration levels, which frequently are significantly above baseline levels. Soil physico-chemical properties, in particular high

contents of organic matter, clay and carbonates, and a neutral pH, favour a low bioavailability of metals. Nevertheless, pore water concentrations in the oxidised substrate can be elevated compared to soil solution of uncontaminated soils, but not to the extent that significant metal leaching would be of concern. The permeability of the substrate is low, the metal sorption capacity is high, and the limited amount of metals that might leach from the site will quickly be sorbed by underlying soil. Cycling of Cd and Zn in the ecosystem is a more important cause of concern. Several plants significantly accumulate metal levels in their above ground tissues above levels encountered in a non-polluted environment. Large differences in metal uptake between plant species and clones were observed, pointing at the importance of vegetation in metal cycling. Through leaf fall of willows and poplars, metals may accumulate in the top soil, where soil dwelling organisms are exposed to the metals. As a result, soil dwelling organisms and small mammals living in these ecosystems accumulate metals in their tissues. This raises concern for a potentially enhanced transfer of metals to the food chain.

Where past research has allowed to gain an appraisal of the extent of metal cycling and accumulation in different compartments of the ecosystem, the effective biological effects and responses caused by the metal contamination are still not well known. Effects of metal contamination on organisms, at the individual level and at the population level, on fitness-related characteristics in different soil dwelling organisms, and influences on population genetic structure and genetic diversity are topics meriting further study. This is required to fully apprehend the implications of the metal contamination, both quantitatively and qualitatively. Amongst other factors, spatial patterns of soil pollution, differences in feeding behaviour of target animals, heterogeneity and temporal trends in metal concentrations in vegetation and organisms, and spatial patterns in food availability will need be included in ecological risk assessment.

Dredged sediment-derived soils represent but one example of contamination for which traditional remediation is not a realistic option because of the moderate pollution levels over extended areas (Meers et al., 2003; Vervaeke et al., 2003). Only a well deliberated use of these sites which is designed at minimizing potential hazards of the contamination, appears a realistic option. Management options for these sites such as wetland conservation, afforestation, short rotation forestry or creation of landscape dikes can only be successful if they are based on a good understanding of the cycling and ecosystem impact of trace metals, and provided site development is monitored in the long-term.

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